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TEACHING FLUID-PARTICLE PROCESSES

A Workshop Report

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Many chemical engineering departments are in the process of revising their curricula, due, in part, to the increased flexibility associated with new criteria approved by the Accreditation Board for Engineering and Technology (ABET) and to input received from alumni and industry. One area that is being considered is fluid-particle technology.

Chemical engineering products in particulate form, or with particulate additives, include pharmaceuticals, paints, fertilizers, ceramics, detergents, juices, magnetic and photographic films, cosmetics, processed foods, etc. Indeed, it has been estimated that more than half of the products of the major U.S. chemical companies are solids.^[1] Still, our courses tend to focus on fluids (gas or liquid) rather than on solids transport, on molecular rather than particulate separations, and on single-phase or homogeneous rather than multiphase or heterogeneous reactions. Several recent articles report on studies that contrast significant educational programs on particle technology in Canada, Europe, and Japan with the relative neglect of this subject in the United States.^[1-6]

Although the need to train chemical engineers in basic particle technologies commonly encountered in industry is becoming more widely recognized, there remains a lag in the development and use of appropriate teaching materials. In light of this, we were asked to arrange a series of workshops on teaching fluid-particle processes for the ASEE Summer School for Chemical Engineering, held in August of 1997 in Snowbird, Utah. The purpose of these workshops was to exchange experiences on fluid-particle educational efforts and to identify existing and proposed materials and approaches that may assist others in the future.

In this article, we summarize the findings and recommendations of the workshop participants. Further details on demonstrations, experiments, simulations, modules, and courses

that may be used to help teach fluid-particle processes are given in the companion articles in this journal issue^[6-11] as well as in related articles from past issues.^[12-18]

OVERVIEW OF WORKSHOP CONTENTS

A list of the three half-day workshops is given in Table 1. The four keynote overviews, two from industry and two from academia, presented broad views of the need for teaching fluid-particle processes and of recent progress to address this need in U.S. chemical engineering curricula. Additional presentations were made on individual courses, lab exercises, simulations, and demonstrations on fluid-particle processes. There was strong audience participation during the discussions that followed each presentation and via breakout groups on the development of teaching materials.

In their keynote presentations, Ralph Nelson (DuPont), Bob Pfeffer (New Jersey Institute of Technology), Ted Knowlton (Particulate Solids Research), and Frank Tiller (University of Houston) noted that the "legacy of neglect"^[2]

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of particle technology in U.S. education is beginning to change.^[6,7] Industry-backed professional societies such as the American Filtration and Separations Society (AFS) and the Particle Technology Forum (PTF) of the American Institute of Chemical Engineers (AIChE) have formed educational committees to promote the development of textbooks, short courses, and other educational tools for particle technology. The Fluid, Particulate, and Hydraulic Systems Program of the National Science Foundation (NSF) has supported several educational projects in this area. Research centers, such as the Engineering Research Center for Particle Science and Technology at the University of Florida, the Particulate Materials Center at Pennsylvania State Uni-

versity, the Particle Technology Center at the New Jersey Institute of Technology, and the Ohio Board of Regents Consortium on Fine Particle Technologies, led by the Ohio State University, also have significant educational components.

Current educational approaches for teaching particle science and technology in chemical engineering curricula fall into three categories:

- *Multicourse sequences or options*
- *Single elective courses*
- *Modules and exercises in standard courses*

Examples of each of these modes were included in the workshop presentations.

U.S. schools (including the City College of the City University of New York, the University of Cincinnati, the University of Florida, New Jersey Institute of Technology, Ohio State University, and Pennsylvania State University) now offer or are planning multiple elective courses on particle science and technology.^[7,11,13] They include a mix of undergraduate and graduate courses and cover topics such as basic particulate mechanics, particle formation, particle characterization, sedimentation, gas and liquid fluidization, filtration, conveying, mixing, cyclones, and hopper design. Due to the interdisciplinary nature of the subject matter, the course offerings are often cooperative efforts of chemical, civil, and mechanical engineering departments.

Several additional U.S. chemical engineering departments offer single elective courses in particle-related subjects such as colloids, fluidization, particle formation, powder technology, fluid-solid flow, particle processing, and suspension mechanics. Example courses were presented in the workshops by Tony Rosato,^[7] Gabriel Tardos,^[13] Sotiris Pratsinis, Rob Davis,^[12] Karl Jacob,^[10] and L.-S. Fan. Many of the elective courses are aligned with the research interests of the instructors and draw relatively small numbers of graduate students and advanced undergraduates. Karl Jacob described a unique undergraduate course on the basics of solids processing, which he team-taught with George Chase at the University of Akron.^[10]

In contrast to the examples cited above, most U.S. chemical engineering departments do not currently offer a course in particle science and technology.^[5] Even so, fluid-particle processes may be introduced in any chemical engineering curriculum by incorporating appropriate modules and exercises in standard courses such as materials and energy balances, transport phenomena, separations, reaction engineering, design, and the unit operations laboratory. During the workshops, Jennifer Sinclair (Purdue) showed how simulation packages can be used to illustrate fluid-particle flows^[8] and George Klinzing (University of Pittsburgh) described several simple demonstrations and laboratory exercises on powder flow.^[9] In addition, the Engineering Research Center for Particle Science and Technology at the University of

TABLE 1

Workshops on Fluid-Particle Processes

WORKSHOP #1

Keynote Overviews

- Ralph Nelson and Reg Davies, DuPont
Industrial Perspective on Teaching Fluid-Particle Technology in Chemical Engineering Curricula
- Bob Pfeffer, New Jersey Institute of Technology
Particle Technology in the Engineering Curriculum—Can We Make it Happen?

Case Studies, Design Projects, and Experiments

- Tony Rosato, New Jersey Institute of Technology
Particle Technology Research-Based Curriculum Development: A Case Study
- Jennifer Sinclair, University of Arizona
Case Studies in Fluid-Particle Flow Using CFD
- George Klinzing, University of Pittsburgh
Pneumatic Conveying: Design, Demonstrations, and Lab Exercises

WORKSHOP #2

Keynote Overview

- Ted Knowlton, Particulate Solids Research
Particle Technology in Industry and the Need for Curricula on Fluid-Particle Technology in Chemical Engineering

Courses on Fluid-Particle Processes

- Gabriel Tardos, City College of the City Univ. of New York
Teaching about Powders and Powder Technology to Chemical Engineering Students
- Sotiris Pratsinis, University of Cincinnati
Particulate Formation Processes
- Rob Davis, University of Colorado
Suspensions and Colloids

WORKSHOP #3

Keynote Overview

- Frank Tiller, University of Houston
Short Courses on Fluid/Particle Processing and Separation, Interfacial Engineering, and Particle Science

Courses on Fluid-Particle Processes

- Karl Jacob, Dow Chemical; George Chase, Univ. of Akron
Undergraduate Teaching in Solids Processing/Particle Technology: An Academic/Industrial Approach
- L.-S. Fan, The Ohio State University
Teaching Gas-Solid Flows from a Particle Technology Perspective

*Reports by Breakout Groups on Development of Course Materials
Wrap-Up Discussion and Plans*

Particle Science and Technology

Florida is developing several ready-to-use instructional modules that are, or soon will be, available for general use.^[11]

At the end of the second workshop, the participants were divided into four breakout groups, based on their interests and expertise, covering topics such as solid-liquid systems (colloids and suspensions), solid-gas systems (powder mechanics and flow), computer simulations of fluid-particle systems, and particle processes (formation, growth, size reduction, and characterization). Each group was given the following charge:

- List current impediments to the teaching of particle technology
- Propose possible solutions to these impediments
- Suggest specific examples of materials that can be used to help teach particle technology
- Present group findings during the third workshop

The findings of these breakout groups, as well as the recommendations made during the ensuing discussion, are summarized in the following section.

SUMMARY OF RECOMMENDATIONS

The different working groups had remarkably similar findings; they are grouped together and summarized in Table 2. First, there is a need for increased awareness of the importance of fluid-particle processes in the various industries that employ chemical engineers. Students in particular need to be shown the value of training in this area through field trips, presentations, written materials, and hands-on experience. Faculty and administrators must also be convinced if significant curricular change is to be effected. Industry and professional groups will need to continue to play a lead role in this regard.

Second, it is difficult to introduce new subjects in the chemical engineering curriculum, which at most universities is already quite full and considered one of the broadest, deepest, and most difficult majors. Moreover, particle technology to many lacks the glamour or attention associated with subjects such as biotechnology, environmental engineering, and microelectronics processing, which are all competing for space. Fortunately, the diverse nature of fluid-particle processes allows for great flexibility in how the subject is addressed. As noted previously, departments may introduce modules, examples, and experiments in existing courses, develop a full course on fluid-particle processes, or offer a special option in particle technology. The last may be particularly attractive for a combined BS/MS degree. The workshop participants recommended that all chemical engineering departments include training in fluid-particle or particulate multiphase processes in some way in their curricula.

Perhaps the greatest impediment to teaching particle technology is the lack of available materials that cover, to a great extent, the relevant interdisciplinary topics. The workshop speakers noted that since there are no suitable textbooks for the courses, they used a reserve list of several reference books and specialty texts that are relevant to various por-

TABLE 2

Primary Impediments and Recommended Solutions for Teaching Particle Technology

Lack of Recognition as Being Important

- Offer presentations and field trips through AIChE student chapters
- Provide co-op opportunities, internships, and independent study projects
- Publish surveys, articles, and videos on particle technology applications
- Use industrial advisory committees to provide input to departments and administrations
- Develop base of national support through ABET, AFS, AIChE-PTF, NSF, and other organizations

Lack of Room in the Curriculum

- Introduce particle technology in freshman and sophomore years through demonstrations and videos
- Include particle technology experiments in lab courses
- Incorporate fluid-particle and multiphase problems in existing core courses
- Develop fluid-particle options for BS, MS, and combined BS/MS programs
- Consider replacing an existing course with one on fluid-particle processes

Lack of Available Teaching Materials

- Assemble and distribute a booklet of homework and example problems
- Make available inexpensive software, CD-ROMs, modules, and demonstration/laboratory equipment
- Create a website with information on courses, problems, and other teaching materials
- Write textbooks that can be used as a resource for short tutorials as well as stand-alone courses
- Use educational grants from industry, NSF, and other organizations to develop teaching materials

Lack of Trained Faculty

- Make teaching materials readily available to faculty
- Hire new faculty with expertise in particle technology
- Offer short courses to educate faculty
- Draw expertise from off campus using long-distance learning media

tions of the courses (a partial list of these books is included in the reference section of this article^[19-39]). To help remedy this situation, Frank Tiller reported that the American Filtration and Separations Society is developing four texts covering particulate and interfacial science engineering, flow through porous media, fluid-particle mechanics, and fluid-particle separations. We strongly urge that any new texts contain a liberal amount of homework and example problems that can also be used in traditional chemical engineering courses. In addition, there is a need to create other teaching materials, such as software, CD-ROMs, short teaching modules, demonstrations, laboratory experiments, and example courses. A partial list of published materials is included with this article,^[7-18] but since many of the materials created by individual faculty are unpublished, it was recommended that a website be created as a resource for such materials.

Finally, the workshop breakout groups all noted that the lack of trained faculty has impeded the inclusion of fluid-

particle processes in chemical engineering curricula. This problem is easily solved. Besides the obvious (though not always easy) approach of hiring new faculty with suitable expertise, there are short courses available to train faculty as well as industry employees. Further, courses can be offered to students by experienced industry representatives or faculty from other campuses through long-distance learning media. In his keynote presentation, Frank Tiller reported on four recent workshops with grants for faculty participation from NSF's Undergraduate Faculty Enhancement Program. Moreover, we believe that most chemical engineering faculty members will be able to include fluid-particle or multiphase processes in their courses once the suitable teaching materials are developed and made available.

WHERE DO WE GO FROM HERE?

Three specific actions have been undertaken as a results of the workshop recommendations:

- This collection of articles in CEE is being published to communicate how fluid-particle processes are being taught in several universities and to provide resource materials for others.
- A website has been initiated for archiving and distributing additional educational materials on particle technology. Ralph Nelson has taken the lead on developing this website, and further information is available in his article with Reg Davies.¹⁶
- A formal request was made to the Education and Accreditation Committee of AIChE to include particulate and multiphase processes in the new ChE ABET criteria, with departments given flexibility on how they provide training in this area.

In the process of reviewing their curricula, we urge all chemical engineering departments to consider how to more fully include particulate and multiphase processes. In addition, we hope that others will make educational materials on particle technology available through publications, presentations, the world-wide web, and software distributors.

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